ランドサットTMデータを用いた、山岳森林地域における植生の区分、植物現存量の推定、炭素収支の評価*

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Estimation and Mapping of the Forest Biomass and Carbon Balance in a Mountainous Region, Based on Landsat TM Data

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Introduction

The canopy type and height of plant are probably the most useful structural variables for quantifying the energy flow and biomass of terrestrial ecosystem. The proportions of energy reflected, absorbed and transmitted for each canopy will vary depending upon its type and condition being sensed. Since the structures and functions of forest canopies are also related to other vegetation parameters such as biomass, age and density in a given forest stand, the spectral information of canopies may give correlative assessments of structural and functional features of the forest stand. The canopy types, heights and densities in the forest stand can be determined by remote sensing methods. Remote sensing techniques have been practically well applied to classifying and mapping of the structural and functional characteristics of vegetation on local, regional and global scales. It have been also used extensively to quantify the amount of local and regional biomass and carbon budget in forest ecosystems contributing to a sinks or sources of carbon. Thus forest biomass and the carbon balances in the tropical and boreal forest vegetation have been focused intensively because of the uptake of CO_2 from regenerating vegetation and the release of one after disturbance or clear-cutting. However, it have been reported little to estimate and map the biomass and carbon balance in forest ecosystems in a local or regional scale, based on the remote sensing data.

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Concepts and Methods for Topographic and Atmospheric Correction

The relationships between spectral responses and vegetation conditions with the topographic variation were extremely important for classification of forest vegetation types. The spectral properities in the mountainous regions, in particular, are much required the topographic correction because of the variation in radiance from inclined surfaces, compared with radiance from horizontal surface.

For there reasons, topographic correction used in this study was practically tested to the relationship between cos r, which is the solar incidence angle relative to the lacal terrain angle, and radiance responses to each vegetation type.

The radiance (L) of any wavelength recorded by the satellite sensor is expressed by :

$$L = T \times A \times R \times \cos r + Lp + Ln, \qquad (1)$$

where T is the atmospheric transmittance, A is the total downwelling irradiance, and R is the reflectance of each target. Lp is the atmospheric path radiance. Ln is the reflectance reflected from the surrounding of any object. However, Ln may be small and difficult to be measured because the variables are easily subject to surrounding effects. The radiance (L) may be regraded as only the change of R values, on the assumption that T, A, Lp and cos r values are constant. Equation (1) can be generally used as the radiance recorded on Landsat TM data. This is the equation for the topographic correction of landsat TM data based on the Lambertian surface in the rugged regions. However, cos r is not constant at the mountainous regions. The reflectance observed in the mountainous regions was inclined to follow the Minnaert's law based on the only slope gradient of target, rather than Lambert's law. Path radiance (Lp) may be also different with the atmospheric conditions. By eliminating the affects of cos r and atmospheric path radiances (Lp) in the mountainous regions, therefore, the corrected radiance (Lc) of the target can be derived as follow :

$$Lc = (L - Lp) / \cos r. \qquad (2)$$

where L is the observed radiance at a target pixel. Thus the corrected reflectance (Lc) can be derived from the equation if the cor r value or slope gradient in the mountainous regions is known. Topographic correction between the cos r or slope data and radiance response was used for classifying the forest vegetation. Topographic correction was clearly effected the bands 4 and 5. The correlation coefficient was higher in the needle forest than in the deciduous forest. This is often caused by the types and variation with the structure of forest canopy and topographic orientation.

The Classification and Mapping of Forest Vegetation

Using the correlation between ground information obtained from vegetation plots and the spectral characteristics of these vegetation plots recorded on Landsat data, the distribution and pattern of vegetation in a given area can be continuously analysed, evaluated and mapped.

The radiance values found in the study area can be classified into 5 types such as deciduous broadleaved forest, pine forest, cedar plantation, clear-cutting and cultivated land, based on the spectral reflectances of Landsat TM data. Forest vegetation types distributed in the areas lower than 800 m (a.s.l) were separated from the non-forest area by the threshold of DN 35 on band 3. The threshold of DN 60 on corrected band 5 divided the forest vegetation into deciduous and coniferous forests, and the coniferous forest was divided into the cedar plantation and pine forest by the threshold of DN 32 on corrected band 5. It is easy for cedar plantation and pine forest to be separated each other, which may be owing to the less transpiration or leaf biomass of pine forest than the cedar plantation.

Classification accuracy for each forest vegetation type based on the topographically and atmospherically corrected Landsat TM data were nearly increased in all classification types, compared with those on the non-corrected Landsat TM data. Classification accuracies for the corrected TM data nearly increased 8 - 11 % in all classification types.

According to the vegetation map, the deciduous broadleaved forest was mainly distributed on the ridge of mountain area more than 800m a.s.l., occupying about 24% in the study area. The cedar plantation was distributed in competition with pine forest stand less than 800m a.s.l., but pine was widely distributed in the lower area than cedar. The distribution area of pine forest and cedar plantation occupyied about 39 and 22.5%, respectively. The cultivated land and clear-cutting occupied 3 and 10%, respectively.

Estimation and Mapping of the Forest Biomass

Vegetation indices (VIs) calculated by the remote sensing data may be probably the most useful single structural variable for quantifying and mapping the distribution and amount of the forest biomass. Vegetation indices (VIs) were calculated from the spectral responses of the corrected Landsat TM data extracted from the training area, and applied to the relationships between VIs and forest biomass. Especially, NDVI and RVI are sensitive indicators for the estimation of pine forest biomass. On the other hand, DVI have a close relationship with the biomass of deciduous broadleaved forest and cedar plantation.

The linear relation between VIs and the above-ground biomass (t ha^{-1}) were derived as follows :

$$\left.\begin{array}{l}\text{Pine biomass} = 3.72\times \text{NDVI} - 3.4,\\ \text{Deciduous biomass} = 7.70\times \text{DVI} - 213.6,\\ \text{Cedar biomass} = -11.26\times \text{DVI} + 541.7.\end{array}\right\} \quad (3)$$

Mean biomass estimated in the pine, cedar and deciduous broadleaved forest based on the above equation (3) were about 143, 135 and 121 t ha^{-1}, respectively. Mean biomass for forest area (2040 ha) within the study area were estimated 135 t ha^{-1}.

Estimation and Mapping of the Carbon Balance

The forest biomass, forest stand age and carbon balance were directly related to the each other. The forest stand age can be estimated by the forest biomass, and carbon balance also estimated from the forest stand age. Based on this reason, the changes of the carbon accumulation and/or biomass in a given area can be systematically or continuously estimated and mapped by the remote sensing method.

In the 100-years period after clear-cutting or harvest in the pine, deciduous broadleaved and cedar forest stands, the total carbon balance are + 95, + 130 and + 100 t C ha^{-1}, respectively, which is nearly equal to the amount of carbon stored within the timbers harvested at clear-cutting. This indicates that harvest and regeneration may contribute to a sink of 400 - 500 t CO_2 ha^{-1}, if most harvested timbers are preserved for period exceeding 100 years after cutting.

Carbon balance map for each or all forest types were produced based on carbon balance between the simulated model and carbon balance estimated from the forest stand age. The mean carbon balance estimated in the deciduous broadleaved forest, pine forest and cedar plantation were about +1.69, +3.05 and +3.39 t C ha^{-1} yr^{-1}, respectively. The mean and total carbon balance for study area were estimated about +2.76 t C ha^{-1} yr^{-1} and $+5.63 \times 10^3$ t C 2040ha^{-1} yr^{-1}, respectively. This indicates that about 4 - 5% of missing sink of atmospheric CO_2 may be sinking at forest area in Japan, if the values obtained in this study would be applied to other forest area in Japan.

As discussed above, a topographically corrected Landsat TM data can be used in classifying and mapping the forest vegetation at the mountainous regions. The relationship between Landsat TM data and forest vegetation data can be also used to correlative assessments for forest biomass, forest stand age and forest carbon balance. This result represents that the stuctural and functional characterictics of forest vegetation types can be quantitatively estimated and mapped from the Landsat TM data.